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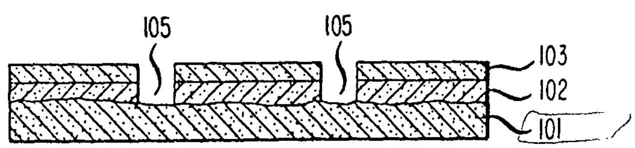
(54) **Mask structure for vacuum ultraviolet lithography**

(57) A mask for vacuum ultraviolet lithography has an alkaline earth halide or alkaline metal halide substrate 101. CaF_2, BaF_2, MgF_2, SrF_2 and LiF are specified. The masking structure, which is opaque in the UV region, comprises one or two layers 102, 103. Layers of polyimide and/or germanium are described which are patterned using a photoresist technique. If more than one layer is present, only one need be opaque to UV.

FIG. 3



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SPECIFICATION

Mask structure for vacuum ultraviolet lithography

This invention relates to the fabrication of very high resolution devices and to mask structures for vacuum ultraviolet lithography, such as lithography wherein the wavelength of the incident radiation is in the range from 1,000 to 2,000 Angstroms.

Lithography is a standard technique for fabricating the minuscule patterns required in integrated circuits and other miniature devices. Pursuant to this technique, a resist-coated device substrate is selectively exposed to a source of electromagnetic radiation via a mask. The irradiated regions of the resist layer suffer a chemical change which makes them either more soluble (positive resist) or less soluble (negative resist) than the non-irradiated regions. A developer is then used to preferentially remove the more soluble resist regions, which are the irradiated regions in the positive resist and the nonirradiated regions in the negative resist. Material may then be etched or deposited in the openings in the resist layer.

Since the cost and efficiency of an integrated circuit is a function of the device size, there have been extensive efforts to develop improved patterning techniques to further reduce the size of patternable features. One development effort has focused on the use of shorter wavelength radiation to selectively expose the resist-covered device substrate as it is well-known that the undesirable interference and diffraction effects ocurring in lithography are directly related to the radiation wavelength. For example, much effort has centered on the development of X-ray lithography, i.e. lithography which uses X rays as the radiation source. The use of X rays while providing smaller pattern sizes requires extensive equipment to generate the radiation at the necessary intensity and the mask structure is extremely fragile.

Another development effort to further improve device substrate patterning utilizes electron beam lithography wherein an electron beam "draws" the device pattern directly on a resist-coated substrate. This procedure can also provide an extremely small pattern size but requires an expensive and complex installation. In addition, in an electron beam lithography, it is necessary that each device pattern be drawn in a sequential point-by-point manner under control of a programming system. Such a procedure is relatively time-consuming and expensive.

According to the present invention there is provided a lithographic mask having over a substrate a material layer opaque to radiation, wherein the substrate is selected from CaF_2, BaF_2, MgF_2, SrF_2, and LiF, and wherein the material layer comprises at least one material layer over the substrate, the layer having at least one opening therethrough, and the material layer being opaque to radiation having a wavelength in the vacuum ultaviolet region of the electromagnetic spectrum.

In embodiments of the present invention, the shortcomings of the prior art are overcome by use of a mask structure for vacuum ultraviolet lithography, i.e. lithography wherein the radiation wavelength is between 1,000 to 2,000 Angstroms. The mask structure comprises an alkaline-earth halide or alkaline-metal halide substrate coated with a patterned material that is opaque to the vacuum ultraviolet radiation. In one disclosed embodiment, the patterned material comprises a layer of polyimide and a layer of germanium. Advantageously, the patterned material is transparent to visible light which facilitates mask-to-device substrate alignment.

It is an advantage of an embodiment that the mask structure is mechanically stable and robust and therefore does not require special fixturing. The invention will be more fully appreciated from a consideration of the following detailed description, when read in light of the accompanying drawing, in which:

Figure 1 is a cross-sectional view of the disclosed mask structure after patterning of an outermost resist layer;

Figure 2 is a cross-sectional view of the disclosed mask structure after patterning of one material layer beneath the resist;

Figure 3 is a cross-sectional view of the disclosed mask structure after patterning of another layer beneath the resist; and

Figure 4 is a cross-sectional view depicting use of the disclosed mask structure for patterning a device substrate.

The specific illustrative mask structure shown in Figures 1-4 comprises a substrate 101 covered with a polyimide layer 102, a germanium layer 103 and a resist layer 104. Resist layer 104 comprises a conventional resist material such as polymethylmethacrylate (PMMA). Substrate 101 can be selected alkaline-earth or alkaline-metal halide materials, i.e., CaF_2, BaF_2, MgF_2, SrF_2 or LiF. The thickness of substrate 101 is selected so that the substrate is transparant to the vacuum ultraviolet radiation wavelength and yet is mechanically robust.

As shown in Figure 1, the desired pattern required on a device substrate (or its photographic negative) is formed in resist layer 104 by electron beam lithography. This pattern is represented by openings 105. Electron beam lithography comprises the successive steps of drawing the desired pattern on resist layer 104 using an electron beam and then removing the irradiated resist using a suitable developer, such as a solution of three parts of ethylene glycol monoethylether in seven parts of methanol.

To minimize electron charging of the mask structure, which can cause deviations of the electron beam from its intended path, a layer of aluminum (not shown) can be deposited over resist layer 104 prior to electron beam patterning. The layer of aluminium can then be removed using a solution of sodium hydroxide in water prior to developing the irradiated resist. It should, of course, be understood that the above-described resist patterning is equally applicable to a negative resist wherein the non-irradiated resist portions are removed by a developer. Moreover, other high resolution lithographic techniques, such as ion beam exposure or x-ray exposure, can be used to pattern resist layer 104.

For precise electron beam patterning of resist layer 104, it is necessary that the thickness of layer 104 be uniform. Variations in resist thickness can cause incorrect exposure of the resist and/or distortion of the delineated resist pattern, Moreover, such thickness variations tend to occur with earth halide or alkali halide substrates as the substrate material is soft and tends to have rough surfaces which are not easily smoothed mechanically. Therefore, polyimide layer 102 is advantageously spun onto substrate 101 to provide a smooth top surface 106.

The patterned PMMA could be used as a mask to etch the polyimide layer directly. However, the etch rate of PMMA in oxygen is greater than that of polyimide. However, the use of germanium layer 103 facilitates transfer of the PMMA pattern to the polyimide as the PMMA etches much slower than germanium in an SF_6 plasma and the germanium does not substantially etch in an oxygen plasma.

After formation of openings 105 in resist layer 104, the mask structure is subjected to reactive ion etching in a sulfur hexafluoride (SF_6) atmosphere. As a result, openings 105 extend through germanium layer 103 as shown in Figure 2. Next, the device substrate of Figure 2 is subjected to reactive ion etching in oxygen which results in extension of openings 105 through polyimide layer 102. The reactive ion etching in oxygen also removes PMMA layer 104. The mask structure after reactive ion etching in oxygen is shown in Figure 3.

Figure 4 shows the use of the mask structure of Figure 3 to pattern a device substrate 401 which is covered with a layer 402 of conventional resist such as PMMA. Layer 402 need only be over device substrate 401, i.e., in contact with substrate 401, as illustrated, or separated from substrate 401 by one or more intermediate layers. Device substrate 401 can be part of any electronic or photonic device. As illustrated, geranium layer 103 is in contact with resist layer 402. Of course, contact between the mask and substrate is not necessary if the radiation emanating from the mask is focused onto the device substrate using a suitable lens. Or, contact between the mask and device substrate is not necessary if a slight loss of resolution is acceptable. Layers 102 and/or 103 are opaque to vacuum ultraviolet radiation 405 so that such radiation only passes through the regions of mask structure 101 that are aligned with openings 105. In addition, the thickness of layers 102 and 103 can be selected to provide the required opacity and yet be transparent to visible light. Such transparency greatly facilitates alignment of the mask to device substrate 401. Thus, resist layer 402 is selectively irradiated in regions 403. Irradiated regions 403 can be removed using a commercially available developer so that the pattern delineated in the mask is accurately transferred to resist layer 402.

Example 1

A mask for VUV lithography was fabricated on a CaF_2 substrate by first spinning on approximately 1500 Angstroms of polyimide, such as XU-218, a trademarked product of Ciba-Geigy Corporation. After baking at 160°C for one hour in air to dry out any solvents, a 300 Angstrom layer of geranium was evaporated onto the polyimide. A resist layer of 1000 Angstroms was then spun on and baked at 130°C for one hour. Advantageously, a layer of 300 Angstroms of aluminum was deposited over the polyimide by vacuum evaporation. A pattern was drawn in the PMMA using an electron beam of a scanning electron microscope. The pattern was then developed in a solution of three parts of ethylene glycol monoethylether to seven parts of methanol. Following developing, the patterned substrate was successively reactive ion etched in oxyyen, SF_6 and oxygen so as to remove resist residue from the exposed germanium areas, etch the germanium and etch the polyimide.

It should, of course, be understood that the above-described mask structure is merely illustrative of a variety of structures which may be deemed by those skilled in the art without departing from the spirit and scope of the present invention. First, while in the disclosed embodiment, the polyimide layer and the germanium layer are opaque to VUV radiation, only one such layer need be opaque. Therefore, the opaque layer can be adjacent to the substrate or separated by one or more intermediate layers which need not be opaque. Finally, the need for the polyimide layer can be eliminated and a layer of germanium opaque to VUV radiation can then be formed directly on to the mask substrate. The elimination of the polyimide layer, however, reduces the accuracy of the mask patterning due to the roughness of presently available earth-halide or metal-halide substrates.

CLAIMS

1. A lithographic mask having over a substrate a material layer opaque to radiation, wherein the substrate is selected from CaF_2, BaF_2, MgF_2, SrF_2 and LiF, and wherein the material layer comprises at least one material layer over the substrate, the layer having at least one opening therethrough, and the material layer being opaque to radiation having a wavelength in the vaccum ultraviolet region of the electromagnetic spectrum.

2. Mask according to claim 1, wherein the layer is adjacent the substrate.

3. Mask according to claim 1, wherein the layer is separated from the substrate by at least one other layer of intermediate material.

4. Mask according to claim 2, wherein the layer comprises polyimide.

5. Mask according to claim 2 or 3, wherein the layer comprises germanium.

6. Mask according to claim 1, wherein a second layer of germanium is adjacent the layer and is oppositely disposed from the substrate.

7. Mask according to claim 6, wherein a third layer or resist is adjacent the second layer and is oppositely disposed from the layer.

8. Mask according to claim 7, wherein a fourth layer of aluminium is adjacent the third layer and is oppositely disposed from the second layer.

9. Method of fabricating a lithographic mask comprising providing a substrate selected from

CaF_2, BaF_2, MgF_2. SrF_2 and LiF; depositing at least one material layer over said substrate, said material layer being opaque to radiation having a wavelength in the vacuum ultravoilet region of the electromagnetic spectrum; and forming a predetermined pattern in said material layer which defines at least one opening in said layer.

10. Method according to claim 9, wherein the material layer is deposited adjacent the substrate.

11. Method according to claim 9, wherein the layer is deposited, separated from the substrate by at least one intermediate layer.

12. Method according to any one of claims 9-11, wherein the layer comprises polyimide.

13. Method according to any one of claims 9-11, wherein the layer comprises geranium.

14. Method of patterning a device comprising, depositing at least one layer of resist over the device substrate, and selectively exposing the resist layer to radiation having a wavelength in the vacuum ultraviolet region of the electromagnetic spectrum using a mask disposed between the resist covered substrate and the radiation, wherein the mask is prepared by the method according to any one of claims 9 to 13.

15. A method of fabricating a mask substantially as hereinbefore described with reference to the Example.

16. A method of fabricating a mask substantially as hereinbefore described with reference to Figure 1, 2 or 3 of the accompanying drawing.

17. A mask prepared by the method according to any one of claims 9 to 14 or claim 15 or 16.

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FIG. 1

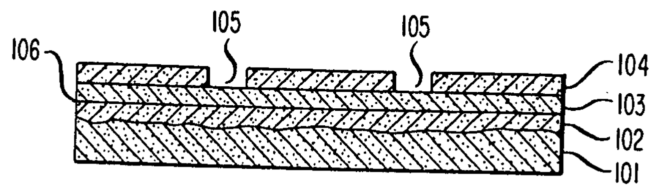

FIG. 2

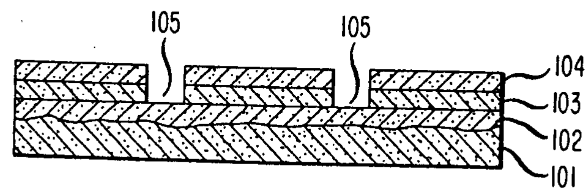

FIG. 3

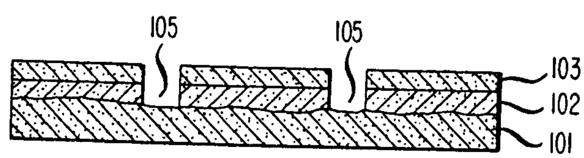

FIG. 4